Chapter 15
Homeostasis

15.1 CONCEPTS IN HOMEOSTASIS

Definition

"Protection of internal environment from the harms of fluctuations in external environment is termed as homeostasis."

Homeostasis keeps internal fluctuations in narrow range as compared to wider external fluctuations with help of various control systems.

Need of Homeostasis

External environment and its components fluctuate continuously. In order to protect internal environment from the harms of fluctuations, organism has to resist and manage these changes by making adjustments. Homeostasis keeps internal fluctuations in narrow range as compared to wider external fluctuations with help of various control system.

Most susceptible components of internal environment that may be affected by fluctuations in the external environments are

- Water
- Solutes
- Temperature
- Nitrogenous wastes as excretory products

Mechanism of Homeostasis

Following three controlling mechanisms of homeostasis

i) Osmoregulation

Mechanism of regulation of solute and water level (by gain or loss) between organism and its environment is called homeostasis.

ii) Excretion

Mechanism of removal of nitrogenous wastes outside the body of an organism is called excretion.

iii) Thermoregulation

Maintenance of internal temperature within a tolerable range is called thermoregulation.

Homeostasis at Cellular Level

In an organism, intracellular environment (environment within cell membrane) at cellular level keeps fluctuating in narrow range as compared to extracellular environment (outside the cell e.g. environment of vascular and other interstitial fluids).

Here in addition to solute and water various essential metabolites, hormones etc. are kept in a required range.

Contribution of Homeostasis in Evolutionary process

Through evolution each organism has acquired a specific set up of internal environment.

Homeostasis is the central requirement in the maintenance of an organism, which compels it to adopt itself in constant changing conditions and contribute in evolutionary process

Homeostasis at Organismic Level

As cell has to cope fluctuations in extracellular environment, similarly an organism has to adapt itself according to fluctuations in external environment.

Control system

For different homeostatic regulations, different control systems have been developed. These living control systems work exactly on the mechanism of physical control system.

Basic Components of Control System

A control system has three components

i) Receptor

ii) Control center

iii) Effector

i) Receptor

Sensor detect temperature change e.g. of increase and signal to control centre for action of cooling system. Or,

Structures, which are specialized for detection of changes in external environment are receptors.

ii) Control Centre

Central structure, which receives signals from receptors and sends messages to effectors to respond to changes is control centre.

iii) Effectors

Structures, which respond to changes in environment are called effectors.

Example of Physical Control System

Consider temperature control system as physical control system. Various components arranged are as follows

i) Sensor (thermometer) monitors temperature changes from a set point and signals to control centre.

ii) Control centre to takes action by switching on heater or cooling unit in response to change in temperature as compared to set point.

iii) Heater or cooling unit shows effect by increasing or decreasing temperature.

Example of Living Control System (in homeostasis)

We consider homeostasis of temperature. In living system there is a set point in temperature regulated (endothermic) animals.

i) Receptors (sensor) detect temperature change e.g. change due to increase, and send signal to control centre.

ii) Control centre acts by activating cooling systems.

iii) Cooling system lowers temperature to set point.

Role of Feedback

Detection of change and signaling effector's response of cooling system is a feedback mechanism.

Above mentioned example is an inverse effector's response i.e. cooling response to heating or warmth sense. Such feedback is termed as negative feedback.

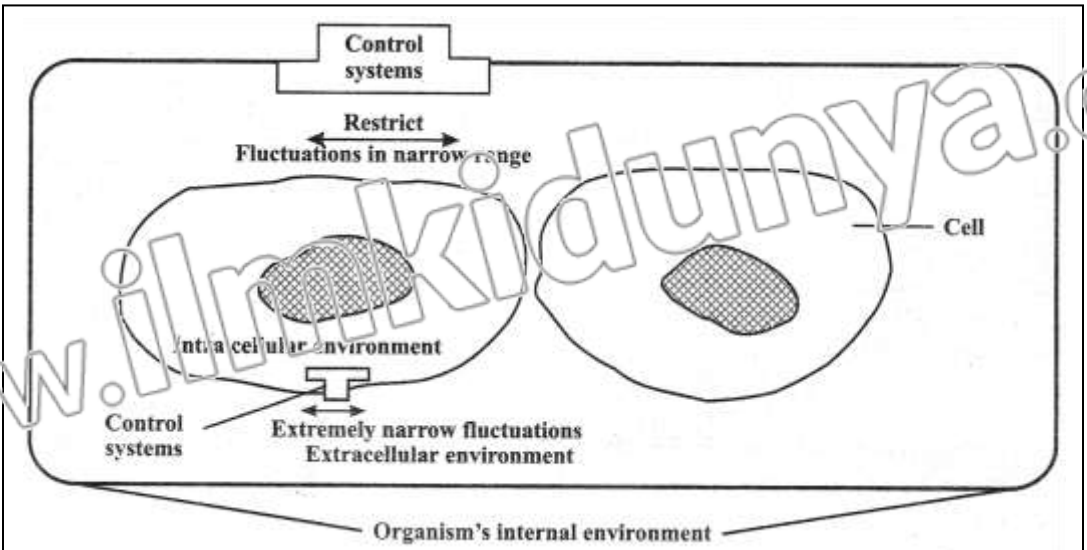


Fig. 15.1 Homeostasis Controlling systems lower fluctuations in internal environments

15.2 OSMOREGULATION

Definition

Mechanism of regulation between organisms and its environment of solute and gain and loss of water called osmoregulation. Or,

Mechanism of regulation of solute and water level is called osmoregulation.

15.2.1 Water Relations of Cell

In the cell, water is solvent of solute. Each cell has been adapted to a defined quantity of water in relation to salts to perform its functions. Homeostatic mechanisms generally maintain this concentration.

15.2.2 Balance of Water and Solute in the Body

Cells consistently encounter changing extracellular environment.

Different conditions related to it are as follows.

i) Hypotonic Environment

If solution in external environment is dilute as compared to cell concentration, it is termed as hypotonic environment.

Hypotonic environment osmotically causes entry of water into the cell and renders the cell solutions diluted. Cell becomes turgid and may be harmed.

To prevent this situation, cell osmoregulates itself to keep water and salts in balance.

ii) Hypertonic Environment

More concentrated external environment as compared to cell concentration is called hypertonic environment.

Hypertonic environment renders cell solutions concentrated and shrinks the cell due to loss of water.

Here also cell osmoregulates itself to keep water and salts balance in plants and animal.

iii) Isotonic Environment

When concentration of external environment resembles to internal environment, it is called isotonic environment.

In isotonic environment, there is no change, so no need of osmoregulation.

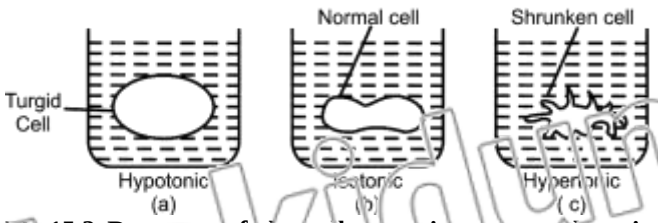


Fig.15.2 Response of the cell to various external environments i.e. different concentrations of solution without any regulation with control system at cell membrane, cell remains in normal state despite differences in its internal to external environments.

15.4 Osmoregulation in Plants

Classification of Plants According to Habitat

Plant habitat changes from aquatic to moderate and then to severely dry terrestrial nature. According to habitat, plants are classified into three types

(i) Hydrophytes

Definition

Plants living in environment with excess supply of water are called hydrophytes e.g. water lilly etc.

Adaptations for Osmoregulation

Hydrophytes have following adaptations to remove extra water.

- Surface area of leaves is very large to transpire water excessively.
- Extensive stomata are present on the upper surface facing the atmosphere to promote loss of water.

Examples

Hydrilla, Chara, Lotus, Water lilly,etc.

(ii) Mesophytes

Definition

Plants living in environment with moderate supply of water are called mesophytes e.g. *Brassica*, rose, mangoes etc.

Adaptations for Osmoregulation

They show osmoregulation as follows.

- In sufficient supply of water, stomata are kept open to promote loss of excess water.
- In restricted supply of water, stomata remain closed to prevent loss of water.

Examples

Brassica, rose, mango etc.

(iii) Xerophytes

Definition

Plants living in an environment with limited supply of water are called xerophytes e.g. cactus etc.

Adaptations for Osmoregulation

They have adaptations for storing and reducing loss of water. Some of adaptations are given below.

- Many xerophytes have small, thick leaves to limit water loss by reducing surface area proportional to the volume.
- Cuticle is thick, waxy and leathery.
- Stomata are on lower surface of leaves and located in depression.
- Some plants shed their leaves during driest season to restrict transpiration completely e.g. cacti. In them stem are photosynthetic organs.
- In rainy season, stem stores water for use in dry conditions.

Examples

Cactus, *Euphorbia*, Alovera, etc.

Fig. 15.3a. A hydrophytic plant **Fig. 15.3b A xerophytic plant**

QUESTIONS RELATED TO ABOVE ARTICLE

Define osmoregulation and describe osmoregulation in plants. (RWP 2021)

15.2.4 Osmoregulation in Animals

Animal cells require more critical balance of water and solutes in the body as they cannot survive with a net water gain or loss. Water continuously enters and leaves the cells. However the quantity of water and solutes is kept in balance.

Approaches to Osmoregulation in Animals

There are two approaches in maintaining balance of water and solute.

(i) Osmoconformers

Animals that do not require adjustment of internal osmotic state are called osmoconformers.

In these animals, body fluids are kept isotonic to the external environment e.g. fishes of marine saltwater environment.

(ii) Osmoregulators

Animals whose body fluid concentrations differ noticeably with outside environment actively regulate to discharge the excess water in hypotonic and excrete salt in hypertonic are called osmoregulators.

- These animals discharge excess water in hypotonic conditions.
- They excrete salts in hypertonic conditions.

15.2.5 Osmoregulation in Different Environments

Osmoregulation has enabled the animals and plants to distribute themselves in wide range of habitats. Osmoregulation by animals in different environments is briefly described below.

(1) Osmoregulation in Marine Environment

- Most marine invertebrates are osmoconformers.
- Among vertebrates, variety is present. Some of the examples are described below.

i) ***Hagfishes*** are isotonic with the surrounding sea water.

ii) Most ***cartilaginous fishes*** maintain lower internal salt concentration than that of sea water. Their kidneys are involved in osmoregulation. They excrete salts through gills and also possess salt secreting organs such as rectal glands. Excretion of salts is by active transport.

iii) Some fishes have low salt concentration and thus live in hypertonic sea water. To prevent excess entry of salty water in body, they retain urea in body fluids in form of ***trimethylamine oxide*** for protection against toxicity of urea.

iv) Some of the bony fishes, which live in marine water lose water from their hypotonic body fluids to hypertonic environment. They drink large amount of sea water and excrete concentrated urine resulting in maximum salt excretion and minimum water loss.

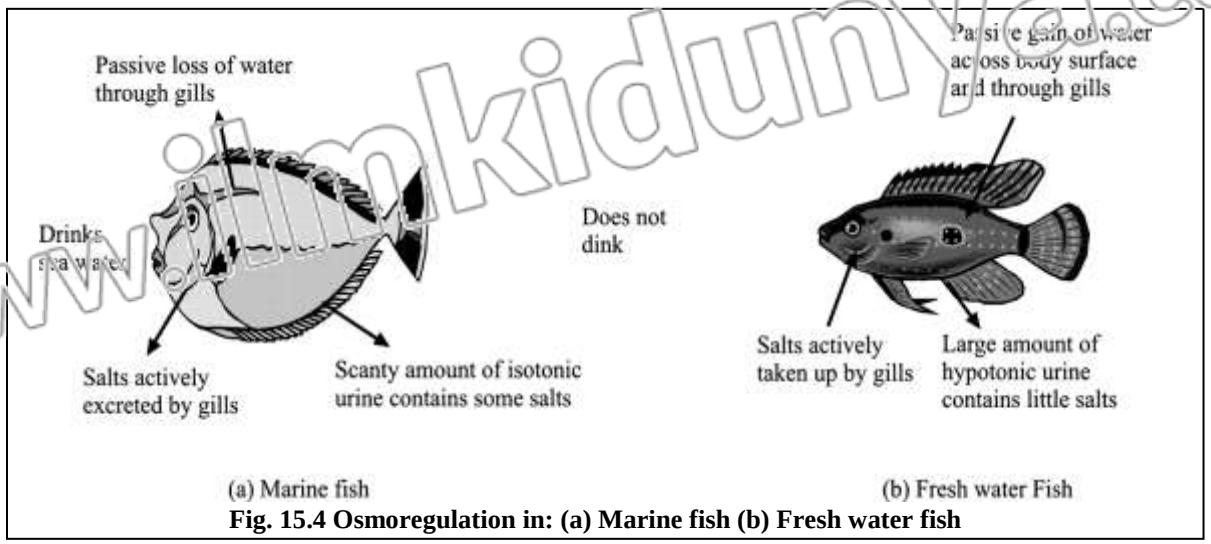


Fig. 15.4 Osmoregulation in: (a) Marine fish (b) Fresh water fish

2) Osmoregulation in Fresh Water Environment

Fresh water animals are constantly facing the osmotic flooding of body fluids and loss of salts. Mechanism of osmoregulation in different fresh water animals is as follows

i) Freshwater ***protozoa***, amoeba and ***paramecium*** pump out excess water by structure contractile vacuoles.

ii) Many freshwater animals including fishes remove excess water by producing large volume of very dilute urine.

iii) Loss of salt in such animals is compensated by using salt containing food and active uptake of salts by gills and skin.

3) Osmoregulation in Terrestrial Environment

The evaporative loss of water leading to dehydration is the major problem for terrestrial life. Arthropods and vertebrates have successfully adopted to terrestrial mode of life. Different adaptations in terrestrial animals for osmoregulation are

i) Terrestrial animals are covered either by ***waxy exoskeleton*** (insects) or ***multi-layered dead keratinized*** skin cells (vertebrate), which prevent loss of water.

ii) Drinking and eating ***moist foods*** compensate the loss of water.

iii) These animals have ***metabolic and behavioural*** adaptations.

iv) Some desert animals feed on seeds of desert plants containing more carbohydrate, which produce ***water of metabolism*** e.g. kangaroo rat. They survive without drinking water.

v) Terrestrial animals ***reabsorb*** moist filtered water through kidney during excretion and produce concentrated urine.

vi) These animals can tolerate dehydration and it differs in various animals. This characteristic is known as anhydrobiosis.

QUESTIONS RELATED TO ABOVE ARTICLE

Describe osmoregulation in marine and fresh water animals.
Describe osmoregulation in animals
Describe osmoregulation in the animals of marine environment. (GRW 2021)
How osmoregulation occurs in fresh water and terrestrial environment. (FSD 2021)

Give osmoregulators adaptation in terrestrial animals. (GRW 2022, RWP 2022)
Discuss the osmoregulators strategies in the animal of terrestrial environment. (SGD 2022)

15.3 EXCRETION

Definition

Elimination of wasteful metabolites mainly of nitrogenous nature is called excretion. It is one of the essential properties of life.

15.3.1 Excretion in Plants

Plants like other living things also undergo excretion as it is essential property of life.

Wastes Produced in Plants

Different wastes produced in plants are

(i) ***Oxygen***, which is produced as a waste product of photosynthesis and removed through stomata.

(ii) ***Carbon dioxide***, which is produced as a waste product of respiration and removed through stomata and water as a waste product.

(iii) ***Water*** produced as a metabolite during respiration is either used by plant or transpired.

(iv) ***Nitrogenous*** and other wastes, which are either stored or removed.

Storage of Wastes Product and Excretion

Wastes can be stored in different plant parts. Some examples are given below.

(i) Vacuole

Large vacuoles store different wastes. When these wastes increase in greater concentration, it leads to crystal formation in vacuole.

ii) Leaves

Certain plant organs also store certain wastes of organic and inorganic nature. Leaves are the most prominent organs for this purpose

Different wastes are accumulated in leaves. With time colour of these leaves changes to yellow and finally they fall off during autumn taking wastes with them.

According to an explanation, yellowing of leaves is not due to removal of chlorophyll but due to accumulation of pigmented compounds prior to falling off. Yellowing is mainly due to toxic materials like heavy metals.

The falling of yellow leaves in autumn is the seasonal time for the plants to get rid of accumulated wastes and because of this reason leaves are said to be ***excretophore***.

iii) Branches and Trunk

Some trees deposit strange chemicals in their branches and trunks especially in old xylem which is no longer used for water transport e.g. in ***ebony***, which produces very black wood in the centre. They are considered waste materials by plant physiologists.

iv) Excretion in Soil

Some plants actively secrete waste compounds into soil commonly using them as chemical weapon against other competing plants e.g. ***conifers***.

QUESTIONS RELATED TO ABOVE ARTICLE

What is excretion? How do plants excrete their wastes?
Give an account of excretion in plants. (GRW 2017, LHR 2018, DGK 2019)
Discuss excretion in plants. (Exercise Question vi)

15.3.2 Excretion in Animals

Excretory Products in Animals

Different excretory products of animals are

i) ***Water***, which is excretory product of animals living in hyperosmotic environment.

ii) ***Salts***, which are excretory products of animals living in hypertonic environment.

iii) ***Nitrogenous wastes***, which are main excretory products produced by breakdown of amino acids and nitrogenous bases or nitrogenous waste metabolites constitute the excretory product.

Formation of Nitrogenous Wastes

Nitrogenous wastes are mainly produced by the catabolism of amino acids by deamination.

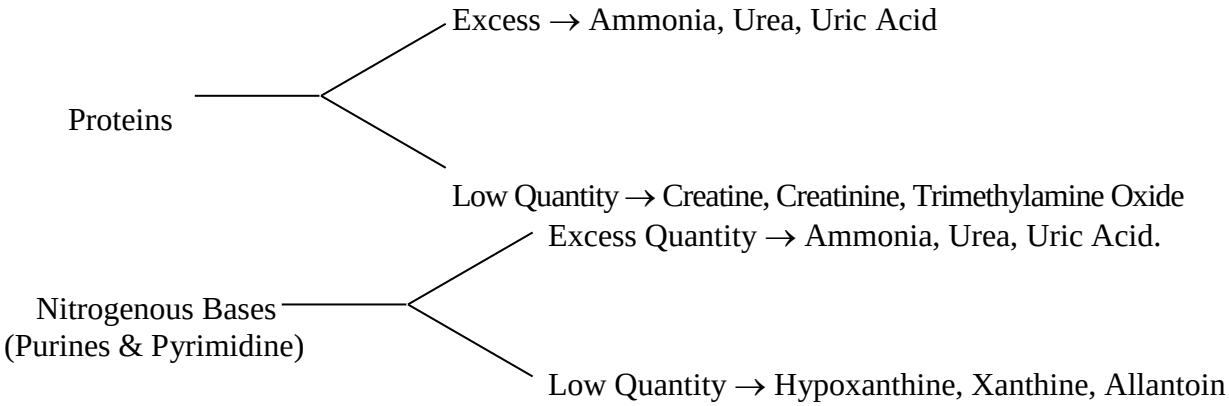
"***Deamination*** is removal of amino group ($-NH_2$) from amino acids." This amino group cannot be stored or reused for recycling of amino acids.

This amino group is dissolved in water and excreted in form of ammonia to avoid toxic rise in plasma or transferred to another molecule for removal or reuse.

Types of Nitrogenous Wastes

Nitrogenous wastes are mainly produced by catabolism of proteins, purines and pyrimidine bases present in nucleic acids.

- Nitrogen produced ***from amino acids*** is excreted mostly as ammonia, urea or uric acid and very small quantities as creatinine, creatine or trimethylamine oxide.
- Metabolism of ***purine and pyrimidine*** bases mostly produces significant amount of nitrogenous wastes of hypoxanthine, xanthine, uric acid, allantoin, urea and ammonia.



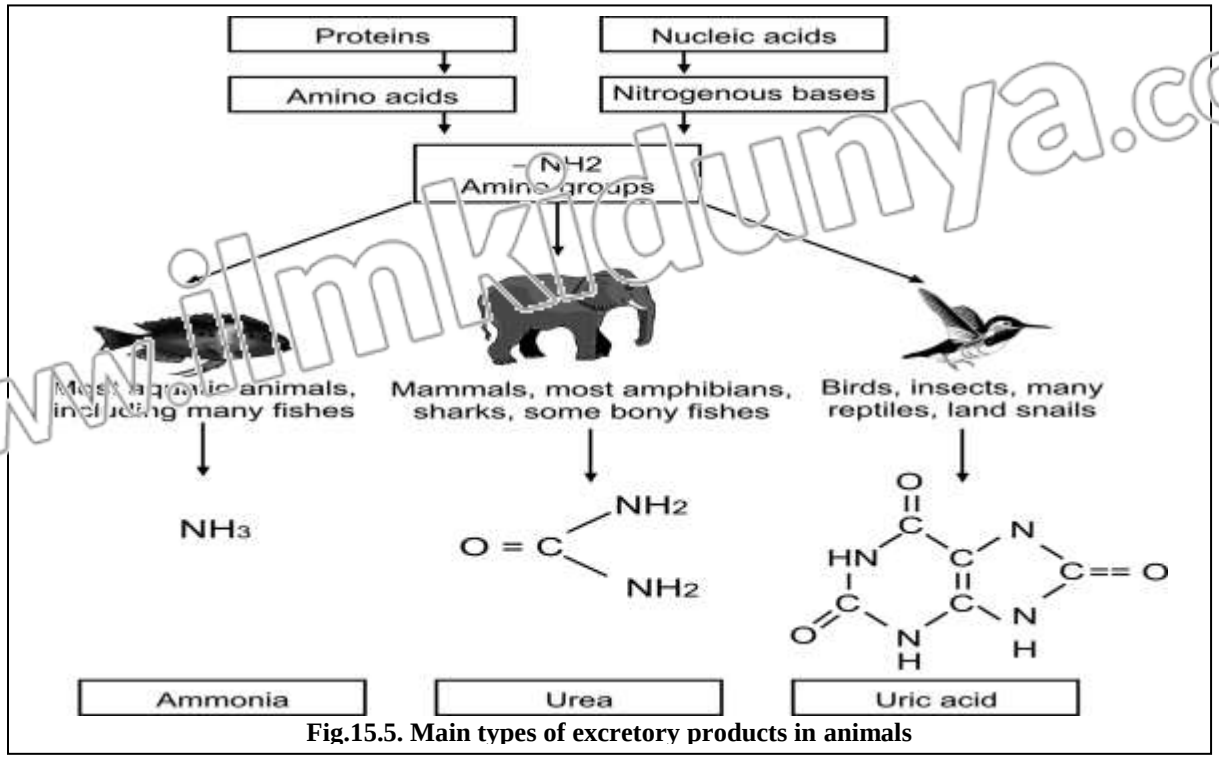


Fig.15.5. Main types of excretory products in animals

Harmfulness of Nitrogenous Wastes

Elevated levels of nitrogenous wastes in body can cause convulsions, coma and eventually death.

15.3.3 Nature of Excretory Products in Relation to Habitats

There are three main nitrogenous wastes, which are produced and excreted according to habitat. These are ammonia, urea and uric acid.

Habitat	Water supply	Nitrogenous waste	Toxicity	Amount of water/1g N	Name in respect to waste	Examples
Aquatic	Maximum	Ammonia	Most toxic	500ml/1gN	Ammonotelic	Hydra, planaria
Terrestrial	Moderate	Urea	Moderate toxic	50ml/1gN	Ureotelic	Human
Terrestrial	Minimum	Uric acid	Less toxic	1ml/1gN	Uricotelic	Reptiles, birds

Ureotely and uricotely are evolutionary adaptations in nitrogenous wastes. These organisms have also undergone adaptations in their excretory structures.

In ureotely, ammonia is metabolically converted into urea by urea cycle.

QUESTIONS RELATED TO ABOVE ARTICLE

How is concentration of excretory products mainlined? Explain. (MTN 2022)

Discuss nature of excretory products in animal to various habitats, specifically in association of water availability. (Exercise Question i)

15.4 EXCRETION IN REPRESENTATIVE ANIMALS

15.4.1 Excretion in Hydra

Hydra, a cnidarian does not have specialized excretory structure. In it waste products simply diffuse into the isosmotic surroundings.

15.4.2 Excretion in Planaria

Introduction

Planaria is a flatworm and belongs to phylum platyhelminthes.

Excretory Substance

They usually excrete ammonia as nitrogenous waste. Freshwater flatworms excrete very dilute urine. The parasitic flatworms, which are isotonic to host environment actively dispose of nitrogenous waste.

Excretory Structures and Their Functioning

Planaria and other flatworms have simple tubular excretory system called protonephridium.

A ***protonephridium*** is a network of closed tubules without internal openings.

Different structural components of a protonephridium are as follows

i) Tubular system spreads throughout the body.

ii) Branches of tubular system are capped by a cellular setup termed as ***flame cells***.

iii) Each flame cell has tuft of cilia, whose beating propels interstitial fluid into tubular system (The beating of cilia look like flickering flame, therefore these cells are called flame cells).

iv) Tubular system is drained into ***excretory ducts***.

v) Excretory ducts open to the exterior through several ***nephridiopores***.

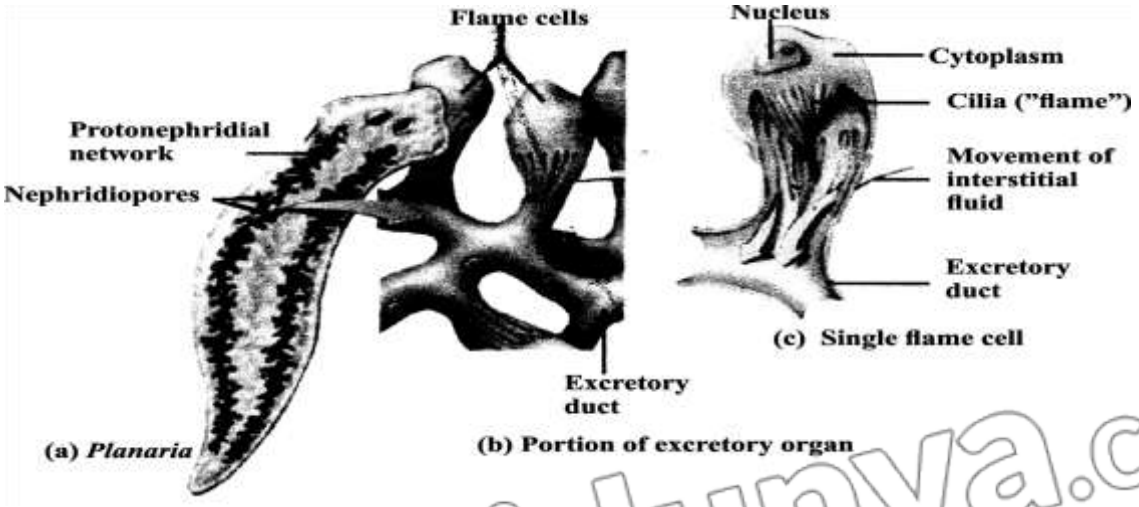


Fig. 15.7 Excretory system in Planaria

15.4.3 Excretion in Earthworm

Introduction

Earthworm is a segmented worm and belongs to phylum annelida. It lives in moist soil.

Excretory Products

Earthworm usually excretes nitrogenous wastes mostly in form of ***urea*** and some in form of ***ammonia***.

Excretory Structures

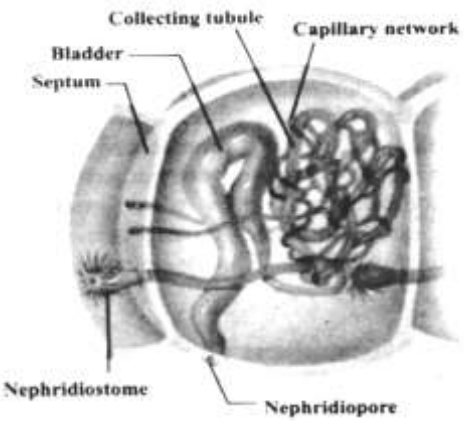


Fig. 15.8 Excretory system in Earthworm

Excretory structures are called as ***metanephridia***. Each segment of earthworm has a pair of metanephridia.

Different components of a metanephridium are

i) ***Nephrostome***, which is internal ciliated opening immersed in coelomic fluid and enveloped by network of capillaries.

ii) ***Tubular part*** consisting of collecting tubules and bladder surrounded by a network of capillaries.

iii) ***Nephridiopore*** through which nephridium opens to the outside.

Mechanism of Excretion

Nephrostome collects coelomic fluid. As fluid moves along the tubule, epithelium reabsorbs the salts from lumen and send to blood vessels surrounding the nephridium. The left over appears as urine containing nitrogenous wastes and excreted out through nephridiopore.

15.4.4 Excretion in Cockroach

Introduction

Cockroach is an insect belonging to phylum arthropoda.

Excretory Products

They mostly excrete nitrogenous wastes in form of uric acid.

> Insects are the only group of animals, which eliminate excretory waste with feces, in all other animals there is no structural and functional relationship between nutritive and excretory

Excretory Structures

Cockroach and other insects have excretory structures, which are adopted to collect excretory products from hemolymph in sinuses through suspended tubular structures called ***malpighian tubules***.

These malpighian tubules are associated with digestive tract through which nitrogenous wastes are excreted. Thus in them excretory and nutritive systems are interrelated.

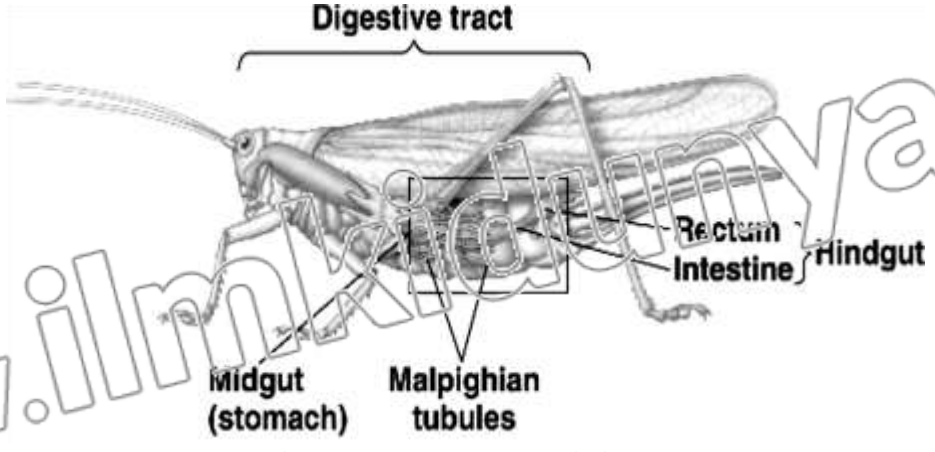


Fig. 15.9 Excretory system in insect

Mechanism of Excretion

Malpighian tubules remove nitrogenous waste from hemolymph. The epithelial lining of the tubules transports solutes including salts and nitrogenous wastes from hemolymph

into tubule lumen. Fluid then passes to hind gut into the rectum. Rectum reabsorbs most of the salts and water, thus nitrogenous wastes are excreted as solid excreta, in the form of ***uric acid crystals*** alongwith feces.

This kind of adaptation in excretion is the success of animals on land with acute shortage of water.

QUESTIONS RELATED TO ABOVE ARTICLE

Describe the excretion in Cockroach. Also draw labelled diagram.
(LHR 2019, SGD 2019)

Give an account of Excretion in Planaria. **(SWL 2019, MTN 2019)**

Explain the process of excretion in Earthworm with labelled diagram.
(GRW 2019, MTN 2019)

Explain excretion in Cockroach with diagram. **(SWL 2022)**

Account the excretory system in Earthworm. **(Exercise Question ii)**

15.5 EXCRETION IN VERTEBRATES

- The ***invertebrate chordate*** (ancestors of vertebrates) have segmentally arranged excretory structures throughout the body like metanephridia in earthworm.
- ***Primitive vertebrate*** hagfishes have kidneys with segmentally arranged tubules.
- In ***present day vertebrates***, kidneys contain numerous tubules (not arranged segmentally), closely associated with dense network of capillaries.

The basic structural and functional unit of kidney is nephron.

15.5.1 Excretion in Human

Common Wastes Produced

Wastes are primarily generated at metabolic level and are called metabolic wastes. Different metabolic wastes are described below.

Sr. No	Metabolic wastes	Source
1	Urea	Produced from the metabolism of amino acids
2	Creatinine	Produced from the muscle creatine.
3	Uric acid	Produced from nucleic acids
4	Bilirubin	End products of haemoglobin breakdown and metabolites of various hormones.
5	Pesticides, drugs and food additives	Ingested into the body.
6	Other toxins	Produced within the body and ingested into the body.

The presence of wastes in body cause serious hazards, thus are eliminated by excretory system.

15.5.2 Excretory Organs

Liver and ***kidney*** are the primary structures for eliminating waste products. ***Skin*** is also involved in excretion but is not considered as an excretory organ. Removal of salts and water by the sweat glands and of sebum by sebaceous glands occurs through skin and seems to be excretory in nature. But the removal of water and salts from sweat glands is for purpose of thermoregulation and sebum on skin is for protection against microorganisms.

LIVER

Introduction

Liver is the central station of metabolism and consequently body's central metabolic clearing house. Liver is involved in homeostasis with interacting other body organ systems.

Functions of Liver

Major functions of liver and their relations with homeostasis are described below.

1) Synthesis

i) Nitrogenous Wastes

It produces ammonia, urea and uric acid from the nitrogen of amino acids.

Urea is the principal excretory products and liver forms it from waste nitrogen. The metabolic pathway involved in the production of urea is termed as ***urea cycle***.

Two ammonia and one carbon dioxide molecules are shunted into the cycle to generate one molecule of urea.

$$2NH_3 + CO_2 \longrightarrow CO(NH_2)_2 + H_2O$$

One ammonia molecule combines with carbon dioxide and already available precursor from previous cycle i.e. ornithine to form citrulline. Subsequently another ammonia combines to form arginine. The arginine is split by arginase to form urea and the precursor ornithine for next cycle.

In this way liver supports the excretory role of kidney.

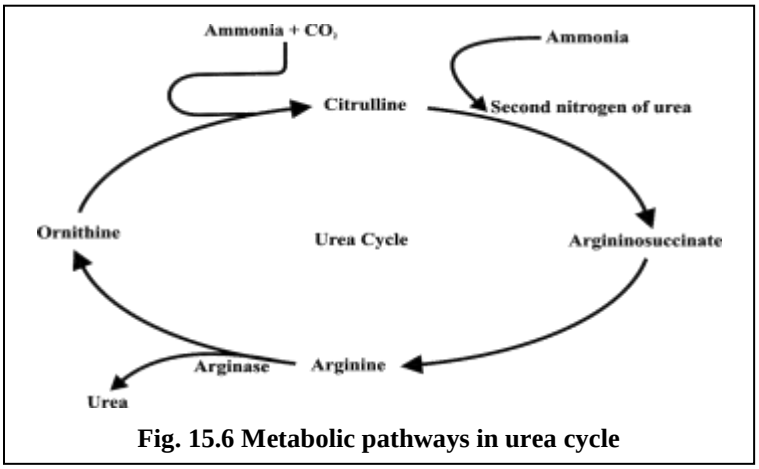


Fig. 15.6 Metabolic pathways in urea cycle

ii) Plasma Proteins

It is involved in synthesis of plasma proteins e.g. prothrombin, fibrinogen, albumin etc. These are also involved in blood clotting and maintenance of osmotic balance of blood.

iii) Bile

It is also involved in production of bile which emulsifies fats in small intestine.

iv) Lipids, Cholesterol & Lipoproteins

Liver is involved in synthesis of lipids, cholesterol and lipoproteins, which regulate blood chemistry, store energy and help to maintain cell membrane.

2) Storage

i) It stores iron, which is required for oxygenation of tissues as constituent of hemoglobin.

ii) It stores glycogen, which acts as energy source.

3) Conversion

It is involved in conversion of excess glucose and lactic acid into glycogen and also conversion of stored glycogen to glucose for energy storage and use.

4) Recycling

Breakdown of old and worn out RBCs takes place in liver and different contents are recycled e.g. iron and similarly other constituents of hemoglobin and oxygenation of tissues.

5) Detoxification

Liver detoxifies many harmful chemicals e.g. nitrogenous wastes, food additives, pesticides, drugs etc and assist kidney in toxin disposal.

Conversion of ammonia into urea is also an example of detoxification. Urea is thus detoxified form of ammonia in urea cycle and can be retained in blood in greater amounts than ammonia. It requires 1/10 quantity of water for removal as compared to ammonia.

QUESTIONS RELATED TO ABOVE ARTICLE

Give the homeostatic roles of liver in the form of a table. (LHR 2021)

Explain the Urea cycle in detail. (MTN 2021)

Give the role of liver as an excretory organ. Discuss its homeostatic function. (DGK 2022)

Give four major homeostatic functions of liver. (LHR 2018, LHR 2022)

Highlight the role of liver as an excretory organ. (Exercise Question iii)

15.5.3 Urinary System

System concerned with formation of urine and its removal outside the body is called urinary system.

It consists of two major components

1) Kidneys
2) Associated tubules

1) Kidneys

- There is one pair of kidneys in humans.
- Each kidney consists of about a million of functional units, nephrons.
- Kidneys or nephrons receive blood from renal artery and pour in renal vein.
- On cut section, two regions are distinct i.e. outer ***cortex*** and inner ***medulla***.
- ***Weight*** of both kidneys is about ***1%*** of total body weight.
- They receive ***20%*** of ***blood*** supplied with each cardiac beat.
- Central cavity of kidney is ***pelvis***, which stores urine.

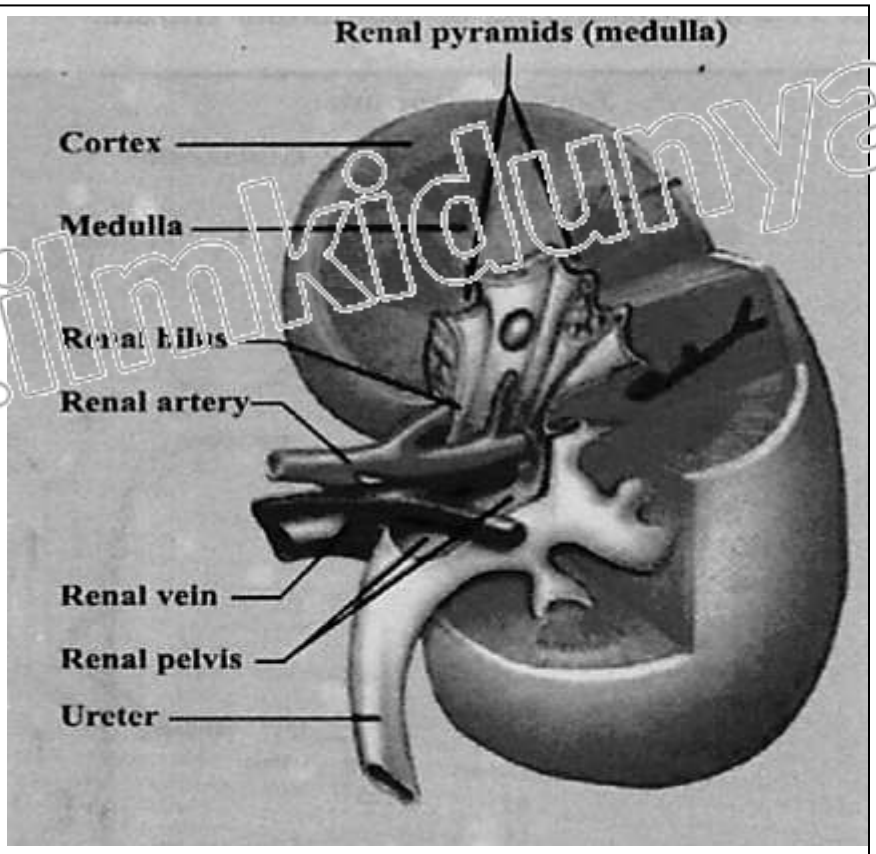


Fig. 15.11. The structure of a kidnev

Functions

a) Major function of kidney is filtration of blood and further processing into urine.

b) It is also involved in ***osmoregulation***.

ii) Associated Tubules

- ***Ureter*** emerges from each kidney, which carries urine to urinary bladder.
- Both ureter open into urinary bladder through ***ureteral orifices***. Urinary bladder stores urine for some time.
- ***Urinary bladder*** empties through a tube called ***urethra*** near vagina in females or through penis in males.
  Sphincter muscles near the junction of the urethra and bladder control the urine.

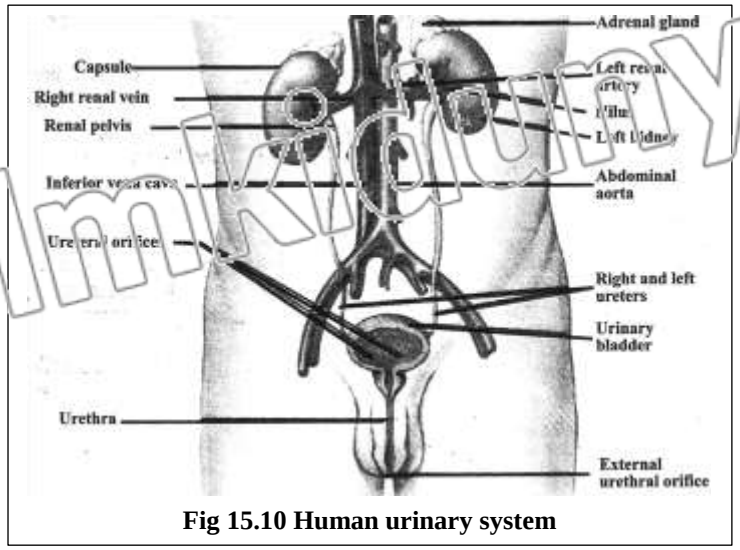


Fig 15.10 Human urinary system

NEPHRON

Definition

Nephrons or urinary tubule is structural and functional unit of kidney.

Types

- Nephrons arranged along the cortex are called as ***cortical nephrons***.
- Nephrons arranged along the border of cortex and medulla are called ***juxtamedullary nephrons***.

Juxtamedullary nephrons are specifically involved in production of concentrated urine.

Structure

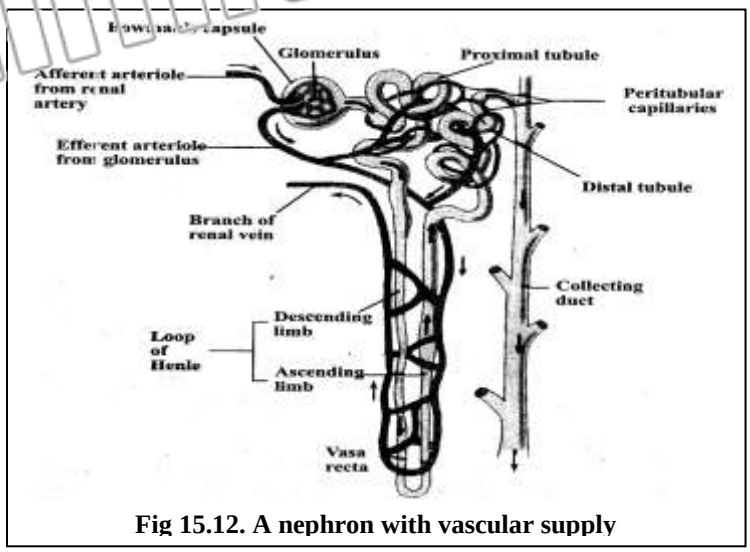


Fig 15.12. A nephron with vascular supply

Different structural components of a nephron are as follows

i) ***Bowman's capsule*** is cup-shaped swelling and inner end of nephron.

ii) ***Glomerulus*** is a ball of capillaries in Bowman's capsule. It receives blood from afferent arterioles. Blood leaves the glomerulus by efferent arterioles.

iii) ***Peritubular capillaries*** is network of blood capillaries around tubular part of nephron intermingle with proximal and distal tubules of nephron.

iv) Tubular part of nephron starts after Bowman's capsule and consists of ***proximal tubule***, ***loop of Henle*** and the ***distal tubule***.

v) ***Vasa recta*** is a loop of vessels (additional capillaries at U-shaped part of juxtamedullary nephron).

Functioning of Nephron

Three major processes are involved in functioning of nephron.

1) Filtration

Blood passing through glomerulus is filtered into Bowman's capsule. This filtration occurs due to two reasons;

i) Walls of glomerulus are ***porous***.

ii) Blood pressure increases causing ***filtration pressure***.

Filtrate appearing in glomerulus is called glomerular filtrate. It contains numerous useful substances such as glucose, amino acids, salts etc. in aqueous solution.

2) Reabsorption

All the useful constituents of the glomerular filtrate are reabsorbed in proximal tubules and when filtrate leaves proximal tubules, it mostly contains nitrogenous wastes.

3) Secretion

Tubular epithelium also secretes substances into lumen by selective process containing mostly hydrogen ions to balance pH value of filtrate and passing through the tubules.

QUESTIONS RELATED TO ABOVE ARTICLE

Give the structure and function of Nephron in human kidneys.
(SWL 2019, KWP 2019, SGD 2021)

Explain the structure of nephron. (LHR 2021)

Explain structure of the nephron with help of diagram.
(GRW 2021, FSD 2022, DGK 2019)

Draw and describe the structure of nephron. Also, discuss blood supply of nephron.
(BWP 2022)

Draw a labeled diagram of a vertebrate nephron with all blood supply. State the function of each p

15.5.4 Concentration of Excretory Products

In restricted supply of water, the conservation of water is the principal function of the body. This is done by concentration of the filtrate by counter current and hormonal mechanism.

i) Counter-Current Multiplier

- As we move from cortical to medullary part, interstitial fluid of kidney is gradually concentrated.
- First there is osmotic outflow of water from the filtrate to interstitial fluid of kidney and then to blood as it passes through descending part of loop of Henle.
- Then ascending part of loop of Henle actively transports Na^+ ions into kidney interstitium to sustain its high concentration.
- This high concentration finally causes reabsorption of water from collecting ducts. At the end urine is converted into concentrated (hypertonic) form.

ii) Hormonal Mechanism

Two hormones are important in this context.

a) ***Aldosterone***, secreted by adrenal cortex, promotes active uptake of sodium in ascending loop of Henle.

b) ***ADH*** (Antidiuretic hormone), secreted by posterior pituitary lobe, controls reabsorption of water in collecting tubules back to kidney.

Gradually increasing osmotic concentration from cortex to inner medulla is a main factor for the production of hypertonic (concentrated) urine in mammals including human.

FOR YOUR UNDERSTANDING

- If there is increased supply of water to body, then there is decreased secretion of ADH and decreased reabsorption of water. Extra water is excreted out through urine and thus urine becomes diluted.
- If there is reduced supply of water to body, then there is increased secretion of ADH and increased reabsorption of water. Amount of water in urine becomes less and it becomes concentrated.

QUESTIONS RELATED TO ABOVE ARTICLE

Discuss Counter – Current Multiplier with reference to concentration of excretory products. (BWP 2021)

15.5.5 Kidney as Osmoregulatory Organ

Mammalian kidney including human is adapted to consume water by over 99.5% reabsorption of glomerular filtrate. Production of various concentrations of urine depending on availability of water shows that kidney functions as an osmoregulatory organ along its excretory role of nitrogenous wastes.

15.5.6 Kidney Problems and Cures

Kidney problems may be due to different factors originating within kidney or outside kidney. Some of the kidney problems are described below.

1) Kidney Stones

Stony materials found at level of kidney are called kidney stones.

Cause

These are mostly formed in ***metabolic diseases***.

Types

Kidney stones are classified on base of specific chemical nature. There are three types i.e.

i) Calcium phosphate stone
ii) Calcium oxalate stone
iii) Uric acid stone

i) Calcium Phosphate Stone

- Its major cause is ***hypercalcemia*** i.e. high level of circulating calcium in blood because of other diseases.
- Its incidence is about ***15%.***

ii) Calcium Oxalate Stone

- Its major cause is ***hyperoxaluria*** i.e. higher oxalate level in blood. Oxalates are present in green vegetables and tomatoes, so may be the source of hyperoxaluria.
- Its incidence is about ***70%.***

iii) Uric Acid Stone

- Its major cause in ***increased uric acid level***.
- Its incidence is ***10%.***

Type of stone	% Age	Cause
Calcium oxalate	70%	Hyperoxaluria (higher blood level of oxalates present in green vegetable & tomatoes)
Calcium phosphate	15%	Hypercalcemia
Uric acid	10%	Increased uric acid level

Mechanism of Formation

Due to increased level, these salts are precipitated out during urine formation and accumulate later to form stone.

Complications

These stones mostly cause urinary obstruction and are further complicated by infections.

Cure

i) Kidney stones can be removed by kidney surgery.
ii) Lithotripsy is commonly used now a day for non-surgical removal of kidney stone.

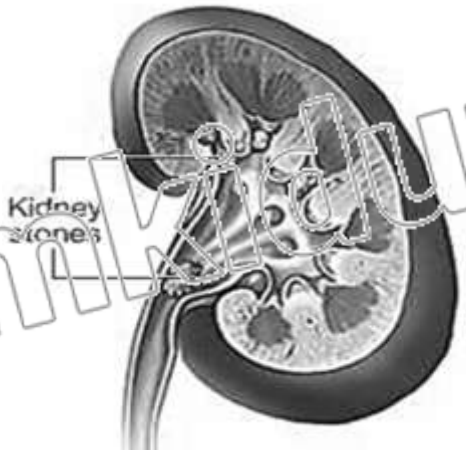


Fig. 15.13 The kidney stones Stone of phosphates are formed and trapped in the pelvis area.

Lithotripsy

It is the technique used to break up stones (in kidney, ureter or gall bladder) by using radiations used for non-surgical removal of kidney stones.

Extracorporeal Shock Wave Lithotripsy

Out of several ways, it is most common.

High concentrations of ***X-rays or ultrasound*** are directed from a machine outside the body to the stone inside. The shock waves break the stone in tiny pieces or into sand, which are passed out of the body in urine.

2) Renal Failure

Definition

Inability of kidneys to perform their functions is called renal failure.

Cause

Major cause is destruction of nephron, particularly its glomerular part, due to various pathological or chemical factors.

Complications

There is an increased plasma level of urea and other nitrogenous wastes in plasma. Rise in urea causes complications of increase in blood pressure, anemia etc.

Cure

Renal failure is cured either by dialysis or kidney transplant.

A) Dialysis

Dialysis is simply cleaning. It is done to remove nitrogenous waste particularly urea in conditions of chronic renal failure where function of kidney is lost completely.

Types of Dialysis

There are two types of dialysis.

i) Hemodialysis

ii) Peritoneal dialysis

i) Hemodialysis

It means 'cleaning of blood'.

Mechanism

In this procedure, blood is circulated through a machine, which contains a ***dialyzer or artificial kidney***. Dialyzer has two spaces separated by thin membrane.

- Blood passes from one side of the membrane and dialysis fluid on the other side.
- The wastes and excess water pass from the blood through the membrane into the dialysis fluid.

ii) Peritoneal Dialysis

Dialysis through peritoneal cavity (lined by thin epithelium called peritoneum) is called peritoneal dialysis.

Mechanism

- Peritoneal cavity is filled with dialysis fluid that enter the body through catheter.
- Excess water and wastes pass through the peritoneum into the dialysis fluid.

B) Kidney Transplant

Dialysis is a temporary measure. In high degree renal failure such as uremia or end-stage renal disease, dialysis has no value and option left as the permanent treatment is only surgical transplantation of a matching kidney.

QUESTIONS RELATED TO ABOVE ARTICLE

Write a note on kidney problems and its curses. (MTN 2021)

Discuss kidney problems and cures. (Exercise Question vii)

15.6 THERMOREGULATION

Regulation of temperature is called thermoregulation.

15.6.1 Thermoregulation in Plants

Different adaptations in plants to low and high temperature are as follows.

1) High Temperature

Harmful Effects of High Temperature

i) It denatures enzymes.

ii) It damages metabolism.

iii) It causes water deficiency resulting in closing of stomata.

Adaptations in Plants to High Temperature

Most plants have adapted to survived under heat stress at temperature of 40˚C and above temperature by different adaptations.

i) They use ***evaporative cooling***.

ii) Cells of these plants synthesize large quantities of special proteins called ***heat-shock proteins***. These proteins embrace enzymes and other proteins and thus help to prevent denaturation.

2) Low Temperature

Harmful Effects of Low Temperature

i) Lipids of membrane become locked into crystalline structure.

ii) Structure of membrane protein is affected.

iii) Fluidity of cell membrane is altered.

iv) Changes in membrane structure affect transport of solutes.

v) Freezing temperature causes ice crystal formation. If ice forms around cell wall, it has no bad effect. If ice crystal within protoplasm perforates membrane and organelles, it causes killing of cell.

Adaptations in Plants to Low Temperature

Plants protect themselves from cold stress by following adaptations.

i) Plants respond to cold stress by increasing proportion of unsaturated fatty acids, which help membrane to maintain structure at low temperature by preventing crystal formation. This adaptation requires time. Thus, rapid chilling of plants is more stressful, than gradual drop in air temperature.

ii) Plants native to of cold region (oaks, maples, roses) have adaptations to change solute composition of cells. These change cause cytosol to super cool without ice formation although ice crystals may be formed in cell walls.

QUESTIONS RELATED TO ABOVE ARTICLE

Describe adaptations for thermoregulation in plants. (LHR 2019)

Describe adaptations in Plants to low and high temperature. (BWP, FSD 2019, FSD 2021)

15.6.2 Thermoregulation in Animals

Body Heat

Temperature of an animal depends upon the rate of change of body heat. This change depends upon

i) Rate of heat production through metabolic processes
ii) Rate of external heat gain
iii) Rate of heat loss

This transfer of heat between an animal and its environment is done in numerous ways.

Heat Gain

Heat is mostly gained through:

i) Infrared thermal radiation
ii) Direct and reflected sunlight transfer heat into the animal

Heat Loss

Heat is mostly lost through;

i) Radiation
ii) Evaporation transfer heat out to environment

Temperature Classification of Animals

Animals show variations in temperature due to environment.

Classification

We classify animals into two ways in relation to heat and body temperature.

A) According to variation in environmental Temperature

We classify animals into two types on base of their body temperature and its relation with environment.

1) Poikilotherms

Animals whose body temperature tends to fluctuate more or less with the changes in ambient temperature (air or water) is change called poikilotherms.

Examples

All invertebrates, amphibians and reptiles, fish.

2) Homeotherms

Animals which maintain their body temperature exposed to changing air or water temperature are called homeotherms.

Examples

Birds and mammals.

Difficulties with above classification

By using above classification, several difficulties arise.

(i) Deep sea fishes (poikilotherms) maintain their body temperature due to constant natural surroundings.
(ii) Similarly lizards (poikilotherm) regulate their body temperature.
(iii) Numerous birds and mammals (homeotherm) vary their body temperature.

For these reasons another classification has been presented depending on source of heat production.

B) According to Source of Heat Production

1) Endotherms

Animals that generate their own body heat through heat production as by product during metabolism are called endotherms.

Examples

Birds, some fishes, some flying insects and mammals.

2) Ectotherms

Animals, which produce metabolic heat at low level and mostly absorb heat from surrounding are called ectotherms.

Examples

Most invertebrates, fish, amphibians and reptiles.

3) Heterotherms

Animals with varying degrees of endothermic heat production and no regulation of body temperature (within a narrow range) are called heterotherms.

Examples

Bats and humming bird etc.

QUESTIONS RELATED TO ABOVE ARTICLE

Discuss the temperature classification of animals. (LHR 2022)

REGULATION OF HEAT EXCHANGE BETWEEN ANIMALS AND ENVIRONMENT

Animals use different mechanisms for heat regulation. These are of structural, physiological and behavioral nature.

1) Structural Adaptations

i) Sub-dermal fatty layer for insulation or pelage.

ii) Presence of sweat glands.

iii) Lungs modified for panting.

2) Physiological Adaptations

i) Regulation of blood flow to skin. Blood flow to skin increases in warmth to dissipate heat and decreases in cold to economize heat loss.

ii) Activation of certain muscles causing plumage fluffing.

iii) Activation of sweat glands for evaporative cooling.

3) Behavioral Adaptations

i) Some animals move to an environment where heat exchange is minimal e.g.

- Squirrels move to burrows in mid-day heat
- Lizards bask in sun to gain heat

ii) Animals control surface area for heat exchange by adjusting their postures.

15.6.3 Thermoregulation in Mammals (Human)

Regulatory Strategies

Mammals including humans maintain their body temperature within a narrow range of about 36-38˚C because of their endothermic characteristics.

Endothermic mechanisms provide heat round the clock and regulate rate of metabolic heat production, balancing it with the rate at which they gain or lose heat from the surroundings.

Mechanisms Involved in Heat Production

Three mechanisms are important in heat production

i) Shivering Thermogenesis

Rate of heat production is increased by increased muscle contraction by movements or shivering, so called shivering thermogenesis.

ii) Non-shivering Thermogenesis

Thyroid hormones trigger metabolism and heat production. This is called non-shivering thermogenesis.

iii) Brown Fat

Some mammals have brown fat, which is specialized for rapid heat production.

Mechanism of Thermoregulation

In mammals, skin is considered as main thermoregulatory organ.
Mechanism of thermoregulation in cold and warm temperature are described below.

1) In Cold Temperature

Mammals have various mechanisms that regulate heat exchange with their environment. Vasodilation and vasoconstriction effect heat exchange and may contribute to regional temperature differences within an animal.

On a cool day

- Humans' temperature may be several degrees lower in the arms and legs than in trunk, where most vital glands are situated.
- Most land mammals respond to cold by raising their furs thereby trapping the thicker layer of still air and it acts as good insulator between animal skin and the surroundings.
- Human mostly rely on a layer of fat just insulating beneath the skin as insulating material against heat loss.
- Marine mammals such as whales and seals inhabit much colder water than their body temperature, have a very thick layer of insulating fat called as ***blubber*** just under skin.

2) In Warm Temperature

- Marine mammals dispose off their excess heat into warm seas by large number of blood vessels in the outer layer of the skin.
- Terrestrial mammals have mechanism of ***evaporative cooling***. The sweat gland activity and the evaporative cooling is one of the major temperature reducing strategy.
- ***Panting***, evaporative cooling in respiratory tract, is another mechanism as represented in dogs.
- Bats use ***saliva and urine*** for evaporative cooling.

QUESTIONS RELATED TO ABOVE ARTICLE

Describe thermoregulation in mammals. (LHR 2017)
Describe the mechanism of thermoregulation in mammals. (GRW 2018)
Describe thermoregulatory strategies in mammals including human in cold temperature. (SWL 2021)
Describe thermoregulatory strategies in mammals including human in cold temperature. (Exercise Question v)

15.6.4 Thermostat Function and Feedback Control in Human

The body temperature regulation in humans is based on complex homeostatic systems facilitated by feedback mechanisms.

- Homeostatic thermostat is present in ***hypothalamus***.
- Hypothalamus responds to changes in temperature above and below a ***set point*** which is 37°C.

Control Mechanism in Increased Temperature

In case of increase in temperature above the set point, following events occur.

- Warm temperature sensitive thermoreceptors in skin, hypothalamus and other parts of nervous system are activated.
- They send signals to system.
- There becomes increase in blood flow to skin to radiate heat.
- There becomes sweat gland activation and sweat is evaporated for the cooling.

Control Mechanism in Decreased Temperature

In cold temperature

- Cold receptors are activated and they send impulses to hypothalamus to inhibit heat loss mechanisms and activate heat conservation mechanisms.
- There is constriction of superficial blood vessels.
- There is stimulation of shivering and non-shivering mechanisms of heat production.

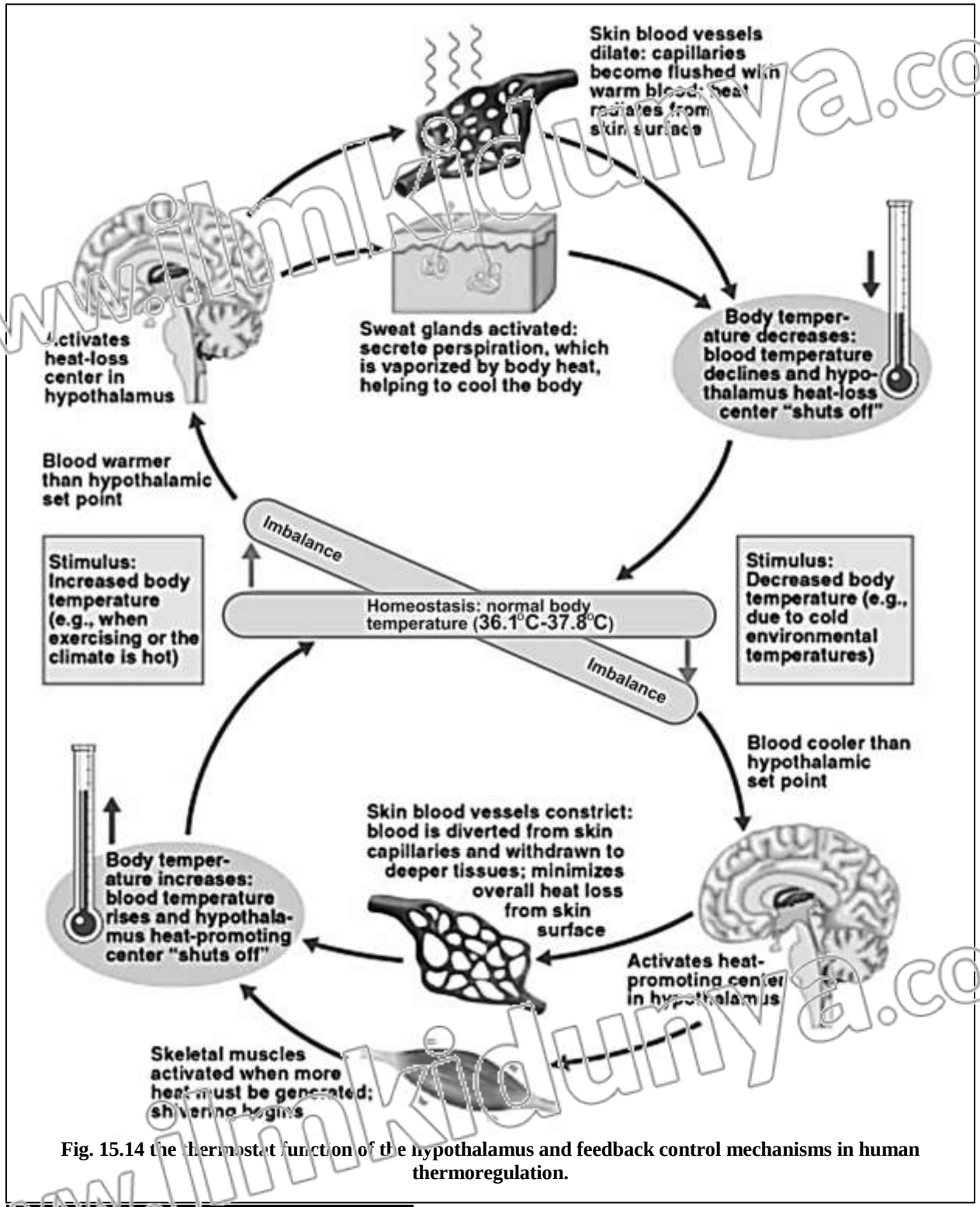


Fig. 15.14 the thermostat function of the hypothalamus and feedback control mechanisms in human thermoregulation.

15.6.5 Temperature in Fever (Pyrexia)

- In bacterial and viral infections leukocytes increase in number. These pathogens and blood cells produce chemicals called as ***pyrogens***. Pyrogens displace the set point of hypothalamus above the normal point of 37˚C. Fever or high temperature helps in stimulating the protective mechanisms against the pathogens.

KEY POINTS

Feedback mechanism:

It is a type of interaction in which a controlling mechanism is itself controlled by the products of reactions it is controlling. In case of negative feedback mechanism, the function of the target organs is inhibited. While in case of positive feedback mechanism, the functioning of the target organ is promoted.

Interstitial fluid:-

The fluid present between the cells is called interstitial fluid. It is directly derived from the blood.

Concentration gradient:-

The difference of concentration between two points in such a way that one point has higher concentration then the other point.

Keratinized cells:-

The cells composed horny substance keratin is called keratinized cells. Keratin is a type of protein. It is present in the outer layer of skin, nail and hairs.

Epithelial tissues:-

The tissues in which spaces between the cells are absent and the cells are arranged compactly are called epithelial cells. The usually forms the lining or organs or outer membrane of the skin.

Connective tissue:-

The tissue in which space between the cells are present are called connective tissue. The cells are suspended in a matrix. In this case, cells are suspended in a matrix, e.g. blood.

Prothrombin:-

It is protein present in blood used for the clotting of blood.

Countercurrent mechanism:-

The opposite flow of adjacent fluid that maximize transfer rate is called counter current multiplier**.** The descending limb of the loop of Henle losses water from the filtrate as it moves downward. So the osmotic concentration of the filtrate increases downward in the descending limb. It becomes maximum at the tip of loop of Henle. But the ascending limb of loop of Henle loses sodium from bottom to top. It reduces the osmotic concentration of filtrate at top of ascending limb.

This indicates the osmotic concentration is increasing in descending limb but increasing ascending limb. This opposite arrangement maximize the reabsorption of water in nephron. Hence concentrated urine is produced.

Bony fishes live in marine water, but they still loss water.

The ancestor of the body fishes are fresh water fishes. The fresh water fishes always loss water as extra water enters into their body. Similarly, the marine bony fishes also excrete water. In order to compensate this loss water they drink water. They remove concentrated urine. So this urine remove extra salts.

Anhydrobiosis and Hydrobiosis:-

The capability of tolerating dehydration in terrestrial environment is anyhydrobiosis whereas the origin and maintenance of life in fluid media is called hydrobiosis.

EXERCISE

Q 1

Fill In The Blanks.

i) _____ is the ability of an organism to regulate its fluid contents.

ii) The detoxification of ammonia to _____ requires the precursor of ornithine.

iii) In kidney nephron is closely associated with network of _____.

iv) In insects salt and water reabsorption takes place in the _____.

v) The antidiuretic hormone acts on _____ to promote reabsorption of water in vertebrate nephron.

vi) The nephrons arranged along the border of cortex and medulla, with tubular system looping deep in the inner medulla, are called _____ nephrons.

vii) The non-surgical procedure of removing kidney stone is termed as _____.

viii) _____ is the homeostatic thermostat in human.

Ans

i) Osmoregulation
ii) Urea
iii) Capillaries
iv) Rectum
v) Collecting tubule
vi) Juxtamedullary
vii) Lithotripsy
viii) Hypothalamus

Q 2 Encircle The Correct Answer From The Multiple Choices.

i) The protection of an internal environment from the harms of fluctuations of external environment is the definition of which of the following?
(a) Osmoregulation
(b) Excretion
(c) Thermoregulation
(d) Homeostasis

ii) The category of the plants that has adaptations of small and thick leaves to limit water loss are called:
(a) Hydrophytes (b) Xerophytes
(c) Mesophytes (d) Halophytes

iii) The environment where the animals produce large volumes of diluted urine:
(a) Hypotonic aquatic
(b) Isotonic aquatic
(c) Hypertonic aquatic
(d) Terrestrial

iv) Which of the following are called as excretophore i.e. contributing mainly in the elimination of wastes in plants?
(a) Stem (b) Roots
(c) Leaves (d) Flowers

v) The excretory product that requires minimum water for its elimination compared to others:
(a) Urea (b) Uric acid
(c) Creatinine (d) Ammonia

vi) The group of animals whose excretory system is structurally associated with nutritive tract:
(a) Vertebrates (b) Earthworm
(c) Planaria (d) Insects

vii) The excretory structures that deliver urine from kidney to urinary bladder:
(a) Urethra (b) Pelvis
(c) Ureter (d) Collecting tubule

viii) The metabolic wastes that are ingested into the body and must be removed:
(a) Pesticides
(b) Drugs
(c) Food additives
(d) All of the above

ix) Which of the following is not endotherm?
(a) Bird
(b) Amphibian
(c) Flying insects
(d) Mammals

x) Name the adaptations from the following that is responsible for shivering thermogenesis:

(a) Structural
(b) Physiological
(c) Behavioural
(d) None of these

Answer key

i	d	vi	d
ii	b	vii	c
iii	a	viii	d
iv	c	ix	b
v	b	x	b

Q 3 Short Questions

i) Differentiate between osmoconformers and osmoregulators.

Ans.

These animals do not require actively to adjust their internal environment and are isotonic to external environment are called osmoconformers.	Animals whose body fluid concentration differ with outside environment and actively regulate to discharge excess of water in hypotonic and excrete salts in hypertonic environment.
These animals live in isotonic environment.	These animals live in hypotonic or hypertonic environment.
Marine invertebrates, hag fishes	Bony fishes, terrestrial animals, cartilaginous fish.

ii) Define anhydrobiosis with an example.

Ans. Definition: Terrestrial animals can tolerate dehydration and it differs in various animals. This characteristic is known as anhydrobiosis.

Example: Desert animals.

iii) Why does filtration take place only at glomerular part of nephron and nowhere else?

Ans. Filtration at glomerular level occurs due to two reasons:

- Walls of glomerulus are porous, so substances can easily pass through it.
- High blood pressure develops at glomerulus that is known as filtration pressure.

iv) Mention two metabolic altered states that generally (70%) cause kidney stone formation.

Ans.

- High blood oxalate level due to increased intake of oxalate leading to **hyperoxaluria.**
- Higher blood oxalate level due to increased production of oxalate.

v) What is renal failure?

Ans. When kidney is unable to filter urea (due to increased plasma level) and nitrogenous wastes, this condition is called renal failure. This occurs particularly due to destruction of glomerular part of nephron.

vi) Account one main adaptation in plants to high and low temperature.

Ans.

- In order to avoid effects of **high temperature**, they have evaporative cooling.
- In order to avoid effects of **low temperature**, they change solute concentration of cells, so that cytosol becomes super cool without ice crystal formation.

Q 4 Extensive Question

i) Discuss nature of excretory products in animals to various habitats, specifically in association of water availability.

Ans (See article 15.3.3)

ii) Account the excretory system in earthworm.

Ans (See article 15.4.3)

iii) Highlight the role of liver as an excretory organ.

Ans (See article 15.5.2)

iv) Draw a labeled diagram of a vertebrate nephron with all blood supply. State the function of each part.

Ans (See article 15.5.3, see fig 15.12)

v) Describe thermoregulatory strategies in mammals including human in cold temperature.

Ans (See article 15.6.3)

vi) Discuss excretion in plants.

Ans (See article 15.3.1)

vii) Discuss some kidney problems with their cures.

Ans (See article 15.5.6)